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LIFE CYCLE MANAGEMENT

Review and downscaling of life cycle decision support tools for the procurement of low-value products

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Abstract
Purpose In this article, we analyze how environmental aspects can be derived from life cycle management instruments for procurement decisions of low-value products. For our analysis, we chose the case of operating room textiles. The review includes the life cycle management instruments: life cycle assessment, environmental labels, and management systems applied within the textile industry. We do so in order to identify the most important environmental decision criteria based on which the procurer of low-value products can decide for the most environmentally friendly option.
Methods We conducted a systematic literature search in the relevant literature databases. We critically evaluate the identified life cycle assessment studies for sound methodology, verifiability, completeness, and actuality. Based on this review, we analyze and compare the results of the three most comprehensive studies in more detail and derive the most important environmental aspects of operating room textiles. In a second step, we extend the operational perspective via the strategic perspective, namely environmental management systems and further existing life cycle instruments such as eco-labels. We then synthesize the gathered information into a decision vector. Finally, we discuss how the gathered data can be further exploited and give suggestions for a more sophisticated assessment.
Results and discussion The review of the existing life cycle assessments on operating room textiles showed that procurers should not base their decisions exclusively on existing life cycle assessments. In addition to problems such as methodological weakness, incompleteness, outdated data, and poor verifiability, the information provided is far too complex to prepare procurement decisions regarding low-value products. Furthermore, the results for the textiles assessed in the existing life cycle assessments are not necessarily transferrable to the textiles considered by the procurer because of restrictive assumptions. Therefore, it is necessary to downscale the available information and synthesize it in an applicable decision support tool. Our decision vector consists of the key environmental aspects water, CO_2, energy, and waste and is completed by environmental management systems, eco-labels, and the countries of origin that matters for environmental and social aspects as well.
Conclusions The decision vector supports procurers when considering environmental aspects in procurement decisions and provides a mechanism for balancing the information between overcomplexity and oversimplification. Therefore, it should be the basis for future development of an eco-label for operating room textiles.

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Abbreviations

bc	Best case
CEN	European Committee for Standardization
CTMP	Chemithermomechanical pulping

CO	Cotton
CO_2	Carbon dioxide
COD	Chemical oxygen demand
DESTATIS	Deutsches Statistisches Bundesamt (German Federal Statistical Office)
e	Equivalent
EC	European Commission
EEL	European Eco-label
EMAS	Eco-management and audit scheme
EMS	Environmental management system
FC	Fluorocarbon
g	Gram
HDT	Hasse Diagram Technique
IEA	International Energy Agency
IFEU	Institute for Energy and Environmental Research
ISO	International Organization for Standardization
kg	Kilogram
l	Liter
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle inventory assessment
LCM	Life cycle management
MJ	Megajoule
NMVOC	Non-methane volatile organic compounds
NO_X	Nitrogen oxide
O.R. textiles	Operating room textiles
PE	Polyethylene
PES	Polyester
PP	Polypropylene
PROMETHEE	Preference ranking organisation method for enrichment evaluations
SMS	Spunbond–meltblown–spunbond
SO_X	Sulfur oxide
uc	Use cycle
VI	Viscose
VOC	Volatile organic compounds
wc	Worst case

1 Introduction

In this article, we analyze how environmental aspects can be derived from life cycle management (LCM) Instruments for procurement decisions regarding low-value products such as operating room textiles (O.R. textiles). Life cycle assessment (LCA) is in general and undisputedly an important source of information for decision support in business contexts (Søndergård et al. 2004; Frankl and Rubik 2000; Guninée 2002; Baumann and Tillman 2004). The first studies evaluating the use of LCM instruments in procurement assessed specific single LCM instruments, including LCAs (Hochschorner and Finnveden 2006; Matthews and Axelrod 2004), eco-labels (Baldo et al. 2009), and environmental management systems (EMS) (Chen 2005). Nevertheless, the use of LCM instruments is still very limited and mainly focused on high-value procurement decisions such as those regarding defense material (Hochschorner and Finnveden 2006) or long-term contracts (Matthews and Axelrod 2004).

We review and discuss the existing LCM instruments and adopt thereby a similar methodology as Nieminen et al. (2007), Nieminen-Kalliala (2003), and Ren (2000). We do so from a procurer's perspective. Beyond doubt, the high degree of complexity associated with LCAs exceeds the resources and capacities of procurers of low-value products, who are responsible for a variety of products, for example in a hospital ranging from textiles to medical devices to computer systems. Conducting an LCA for a low-value product is comparable to using a sledgehammer to crack a nut. In our case, O.R. textiles only represent a marginal fraction of the total procurement volume of a hospital (ca. 3–5 %). In Germany for example, where hospitals spent more than 77.1 billion Euros in 2009, 2.3–3.8 billion Euros were invested in the procurement of O.R. textiles only. Or to take another perspective: in 2009, 14.3 million surgeries were performed in German hospitals, all of them using O.R. textiles and causing related energy, material, and financial flows (DESTATIS 2011). Assuming that four gowns and four drapes are used in each operation, this amounts to 57.2 million gowns and drapes used annually, a number that indicates the relevance of environmental aspects to O.R. textile use. In any case, the time and resources which procurers can dedicate to prepare a procurement decision concerning operating room textiles are very limited. Thus, the information about the environmental aspects of the product must be condensed, disclosing the central ecological aspects of the product under consideration in a few indicators. Several approaches propose simplified LCAs in order to reduce complexity and increase applicability (Hochschorner and Finnveden 2003; Hur et al. 2005). Moreover, the increasing attention to one-dimensional Life Cycle Instruments such as carbon or water footprints reveals this need for simplification (Schmidt 2009; Finkbeiner 2009; Feifel et al. 2010). As Klöpffer and Heinrich (2009) underlined in their expectations for *The International Journal of Life Cycle Assessment*, it is necessary to bridge the gap between the engineering side of LCM and the actual application of the method in daily decision-making processes. The task at hand is to downscale the central information from several LCM instruments and information sources such as existing LCA studies, environmental management systems, labels applied within the textile industry, and information on the countries of origin and synthesize them in a decision vector.

O.R. textiles, e.g., surgical gowns and drapes, are used in hospitals to protect patients and hospital staff from contamination and infection. Surgical gowns are worn by surgeons, nurses, and other hospital staff. Surgical drapes are used to cover the patient and instruments. The specifications for such operating room textiles are defined in the European Committee for Standardization (CEN) standard 13795 1-3 on hygienic requirements for operating room textiles. The standard is decisive for the definition of the functional unit of operating room textiles. It allows, for example, for the comparison of different systems, such as single-use textiles and reusable textiles. A typical life cycle of operating room textiles is outlined in Fig. 1.

The main difference between single-use and reusable textiles is that reusable textiles will be washed and sterilized after one use cycle (uc) to be re-used 75[1] times, whereas single-use textiles are used once and subsequently disposed. Single-use textiles are mainly made of non-woven materials. Possible raw materials for non-woven textiles are various polyester (PES) and pulp[2] mixtures, polyester and viscose mixtures, or pure polyethylene (PE). The different mixtures are combined in alternating layers of spunbond and meltblown webs. The spunbond–meltblown–spunbond (SMS) combination describes a textile that is layered spunbond–meltblown–spunbond. Reusable textiles may be made of pure polyester in microfiber textiles, a mix of cotton (CO) and polyester in blended fabrics, or a combination of pulp, polyester, and polyethylene in laminate textiles. Some textiles are treated with an additional fluorocarbon (FC) biocidal chemical or other finish to improve the barrier function of the textile. Textiles made of pure cotton do not fulfill the requirements of the CEN standard 13795 1-3 but are sometimes still used in hospitals as a first layer and combined with drapes that comply with the standard.

2 Methodology

The overall goal of our analysis is to derive key decision criteria for an environmental assessment in the purchasing process and to combine it in an applicable decision support vector on which decision makers can rely in purchasing low-value textile products. Therefore, we derive the central ecological aspects for the green procurement of O.R. textiles from existing LCM instruments and synthesize them. We first compile LCA studies of O.R. textiles by conducting a systematic literature search of databases (among them: Academic Search Complete, Business Source Complete, EconLit, ScienceDirect, Web of Science, Google Scholar, Karlsruhe Virtual Catalogue, Medi, Apollit, Chinal, Scopus, and Ulidat, using keywords such as LCA, life cycle assessment, O.R. textile, medical textiles, surgical gowns, etc.). Consequently, the review of the LCA studies is quite complete and recent, covering the most relevant LCA studies of O.R. textiles. From the perspective of a procurer, an LCA on O.R. textiles would ideally give an overview of the entire industry and consider all available product alternatives, including single-use or reusable textiles, the different manufacturing methods, and the various input materials in such a way that verifiable conclusions can be drawn regarding which product yields the best environmental performance. Therefore, we critically evaluate the identified LCA studies for sound methodology, verifiability, completeness, and actuality.[3] Based on this review, we analyze and compare the results of the three most comprehensive studies in more detail and derive the most important environmental aspects of O.R. textile. The results reflect the current state of available knowledge on the environmental aspects of O.R. textiles and pave the way for a future eco-label on O.R. textiles. In a second step, we briefly review further existing life cycle instruments such as environmental management systems and eco-labels. Finally, we add the countries of origin to reflect the conditions of production and synthesize the gathered information into a decision vector. Applying our decision vector to two exemplary cases, we demonstrate how the decision vector can aid the buyer in the green procurement of low-value products.

3 Results

3.1 Review of LCAs

In our systematic literature review, we identified eight LCAs on O.R. textiles: Brune and Krauch (1988), Schorb (1990), Institute for Energy and Environmental Research (IFEU) (1996), Jäger (1996), Dettenkofer et al. (1999), Schmidt (2000), Eriksson and Berg (2003), and Ponder (2009). Our analysis focuses on the five German studies and the English studies of Schmidt (2000) and Ponder (2009). We exclude the Swedish study by Eriksson and Berg (2003) because of the language barrier, but the English abstract proves that the findings do not contradict the findings of the other studies. An overview of the identified studies is given in Table 1.

The LCA study of Brune and Krauch (1988) was edited by the Hohenstein Institute. It compares two reusable drapes (Gore-Tex/PES, CO/PES) with a single-use drape (pulp/chemithermomechanical pulping, CTMP). The results are

[1] This number varies in the LCA studies from 30 to 100 use cycles. Experienced textile researches assume that 75 use cycles are a realistic number.

[2] Pulp can be produced by the chemicothermomechanical pulping method. The wood is firstly softened by the use of chemicals and further decomposed with thermomechanical energy.

[3] Werner and Richter (2007) used similar criteria.

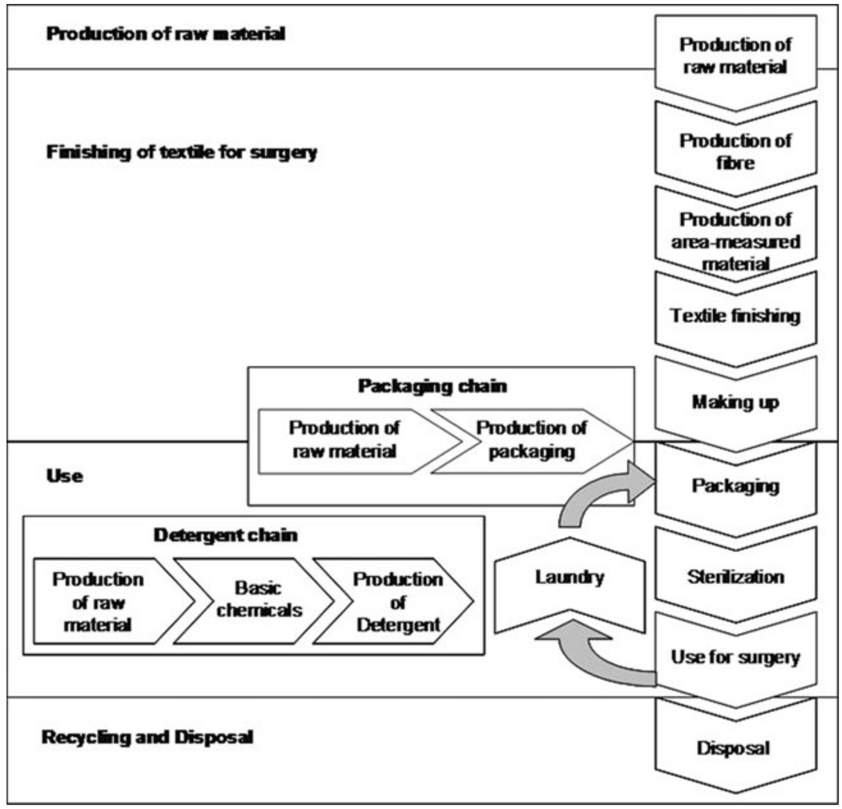

Fig. 1 The life cycle of O.R. textiles is determined by their reusability. The laundry and sterilization phases of the life cycle are not applicable for single-use textiles. For an explanation of the textile production processes, see Albrecht et al. (2002) or Slater (2003)

summarized in a life cycle inventory. A life cycle impact assessment was not conducted. Unfortunately, the cutoff criteria and the data quality remain largely unclear. Other weaknesses of the study are the poor verifiability of the data and the allocation procedures.

The LCA study of Schorb (1990) is the second edition of an LCA study edited by the IFEU originally published in 1988. Aside from minor changes, the status of the data still refers to 1988. The study compares one single-use drape (pulp/CTMP) with two reusable drapes (laminate, CO/PES/FC). The main weakness is that the data are outdated. The reference list of the study mainly refers to data from the 1970s and early 1980s.

The LCA study of Jäger (1996) was published as a short four-page summary edited by the Hohenstein Institute, but we could compare the published results with the confidential 72-page final report. The LCA study was conducted by a consulting company on behalf of Rentex, a producer of reusable O.R. textiles. It compares the Rentex reusable textile (laminate) with an unspecified single-use textile (pulp/PE). The objective of the study is (besides the comparison of single-use and reusable textiles) to optimize the product through the identification of environmental strengths and weaknesses of the assessed textile. The functional unit is a set of O.R. textiles containing several drapes and adhesive to repair them. The main weakness of this study is the passive handling of the poor data availability. While the study could have relied on data from the manufacturer in the case of the reusable textile set, it had no access to reliable data on non-woven material for the single-use textile; it instead used data for pulp.

The IFEU (1996) LCA study is one of the most complete LCA studies on O.R. textiles. It is based on Schorb (1990), but updated and completed with additional textiles. The LCA evaluates drapes and gowns on behalf of a producer of non-woven single-use O.R. textiles. The draft version of the International Organization for Standardization (ISO) standard was cited and applied in an exemplary manner. The IFEU based its analysis on the software Umberto. The sponsor of the study is a producer of single-use textiles, and thus, the study could potentially be critiqued as biased. However, the traceability of the study invalidates this concern. The strength of this study is the access to non-woven data via the sponsor of the study. Furthermore, the study gives a good overview over the entire product range. It compares cotton, cotton/PES, microfiber, and non-woven textiles.

The LCA of Dettenkofer et al. (1999) was published in the German medical journal *Der Chirurg* in cooperation with the Öko-Institut and the University Hospital Freiburg. The objective of the study was to evaluate a single-use drape (pulp/PE) and reusable cotton drapes in combination with single-use pulp/PE drapes. The authors regret poor data availability. They rely mainly on secondary data and supplement it with data from the manufacturer. Referring to the ISO standard, the methodology seems to be appropriate but

Table 1 Overview of the status quo of LCA studies on O.R. textiles and their quality

Study	Material		Functional unit	Environmental winner	Uc of reusable textiles	Methodology	Verifiability	Completeness	Recency
	Reusable	Single use							
Brune and Krauch (1988)	Laminate CO/PES/FC	Pulp/CTMP/PE	1 kg textiles	Reusable	100	Poor	Poor	o.k.	Poor
Schorb (1990)	CO	Pulp/PE Pulp/PE	1 operation	Single use	80	Poor	Poor	o.k.	Poor
Jäger (1996)	Laminate	Pulp/PE	O.R. set	Reusable	80	o.k.	o.k.	o.k.	Poor
IFEU (1996)	CO CO/PES Microfiber	Pulp/PE/PES	1 operation	Differentiated	30–75	Good	Good	Good	Poor
Dettenkofer et al. (1999)	CO/PES	Pulp/PE	1 operation	Reusable	80	o.k.	Poor	Poor	Poor
Schmidt (2000)	CO/PES PES Laminate	Pulp/PES Pulp/PES/PE	1 gown	Reusable	(20-) 75	Good	Good	Good	o.k.
Eriksson and Berg (2003)	Laminate	Pulp/PE	1 gown	Reusable	–	–	–	–	–
Ponder (2009)	CO/PES	PP SMS	1 gown	Reusable	75	Good	o.k.	Good	Good

CO cotton, *CTMP* chemithermomechanical pulping, *FC* fluorocarbon, *PE* polyethylene, *PES* polyester, *PP* polypropylene, *SMS* spunbond–meltblown–spunbond

cannot be evaluated in more detail because of the briefness of the article (six pages).

Schmidt (2000) was commissioned by the European Textile Services Association by dk-TEKNIK Energy & Environment in Denmark. Only the final results of the impact assessment are presented in the English translation. For the results of the single life cycle steps, the study refers the reader to the original data sources. The research followed ISO 14040 standards and is characterized by its innovative handling of the lack of available data by defining worst- and best-case scenarios representing the worst and/or best assumptions. The study is verifiable, complete, and the most up to date of all the studies in the review. The only disadvantage is the exclusion of drapes. It compares three reusable gowns (CO/PES/FC, PES/FC, PES/laminate) and two single-use gowns (pulp/PES/FC, pulp/PES/PE).

Ponder (2009) represents the final results of a dissertation submitted to the Graduate Faculty of North Carolina State University. The dissertation, entitled "Life Cycle Inventory Analysis of Medical Textiles and Their Role in Prevention of Nosocomial Infections," assesses "options for the biocidal chemical, compare the reusable garment with a disposable garment, and assess the use of a biocidal finish in a hospital setting." The study compares polypropylene SMS single-use gowns with reusable gowns made of cotton and polyester. The study is the most recent and complete. The only disadvantage is that the data sources are not directly traceable. The results in Table 4 are presented in a way that makes them comparable to the results of IFEU (1996). For more detailed data, we refer to the original publication.

One major problem common to most of the studies was a lack of data. The production of non-woven fabrics proved to be a particularly weak point for all of the studies except the study from IFEU (1996). The sources of Ponder (2009) are not reported and therefore cannot be evaluated. Nevertheless, the lack of data was confirmed by a complementary literature review on the process-module level (Mielecke 2006). As all of the single-use textiles are non-woven, the lack of data is critical.

Most of the studies are weak in their verifiability and methodology (see Table 1). The comparability is in general low because the functional unit varies from 1 kg of textile (Brune and Krauch 1988), one operation (Schorb 1990; IFEU 1996; Dettenkofer et al. 1999), one textile (Schmidt 2000; Eriksson and Berg 2003) to one O.R. set (Jäger 1996). The number of use cycles of the reusable textiles varies from 20 to 100, whereas nowadays 75 use cycles are typical. The disparate scopes, i.e., product systems, complicate any attempt to deduct transferable conclusions for the procurement of O.R. textiles. In light of the fast-evolving textile industry in terms of CSR and innovation (Perry and Towers 2009; Llach et al. 2009), the outdated status of most of the studies is another weakness. The only three studies that are

sufficiently verifiable, complete, and apply a current methodology are the LCA studies of Schmidt (2000), IFEU (1996), and Ponder (2009). The review of existing LCAs also shows from a procurer's point of view that the results of the textiles assessed in the LCAs are not necessarily transferable to the textiles considered by the procurer because of restrictive assumptions. For example, if the LCA assesses a CO/PES gown but the procurer must decide on a microfiber drape, no distinct conclusions can be drawn.

3.2 Key indicators of environmental performance

The objective of this section is to derive key indicators for the overall environmental performance of O.R. textiles. Therefore, we use the results of the three most comprehensive LCA studies on O.R. textiles (Schmidt 2000; IFEU 1996; Ponder 2009) for this analysis. Their results are summarized in Tables 2, 3, 4, and 5.

The differences between single-use and reusable gowns (see Tables 2 and 3) and drapes (see Table 4) are obvious. In nearly every impact category except water consumption, reusable gowns have lower values than single-use gowns. One might conclude that reusable O.R. textiles are always better than single-use textiles, but Table 5 shows that there are significant differences between gowns and drapes. The reusable microfiber drapes show higher values for the impact categories (cumulated energy consumption, CO_2, VOC, NO_x, COD, and waste) than the single-use drapes in the case of 30 use cycles. A higher number of use cycles will change this result, but nevertheless, it underlines the importance of distinguishing between drapes and gowns.

In Tables 2 and 4, the reusable gowns prove to always have the lowest value of all gowns in almost every category except water consumption; cotton gowns consume the most water. Even if the pure cotton gown in Table 2 must be excluded, because it no longer fits the hygienic requirements of CEN standard 13795 1-3, water remains an important differentiating factor because it makes apparent the trade-off between higher water consumption and other environmental impacts such as increased energy consumption or CO_2 emissions. Thus, water consumption should be considered in the decision vector.

Comparing the results of gowns in Table 2 with drapes in Table 5, we see a considerable change in the distribution of the lowest values. Whereas in Table 2 the single-use gowns show no lowest values in the category except for water consumption, the values for CO_2, COD, and waste change from the highest value in the row to the lowest value in the row in Table 5. In order to consider these differences between drapes and gowns, we integrate CO_2 and waste as key environmental aspects in our decision vector.

Especially in Tables 2 and 5, we see significant variations depending on the assumptions made as to the number of use cycles, indicating a high sensitivity to changes in the number of use cycles. Therefore, the functional unit of the decision vector has to be defined in relation to the number of use cycles. To reflect energy scarcity and price sensitivity, we also include energy consumption, which aids the decision maker in the integration of economic variables. Based on a comparison of the current use of LCAs on O.R. textiles, we determined the four key operational environmental aspects of O.R. textiles to be CO_2, water, waste, and energy.

After having derived energy, CO_2, water, and waste as key operational performance indicators for O.R. textiles from the existing LCAs, additional information on the countries of origin might enhance the decision process: Due to energy politics, the energy mix is different in different countries (IEA 2011) leading to different carbon footprints (Hertwic and Peters 2009). Both energy mixes and carbon footprints can be calculated using databases available via the internet.[4, 5] Water use can be assessed in relation to water scarcity in the countries of origin[6] (Hoekstra and Mekonnen 2011); waste[7] and wastewater[8] treatment might differ due to different political and technological framework conditions. Consequently, two possibilities to consider the countries of origin are viable: first, the procurer can integrate this information as a nominal variable and use it for specific strategies like regional procurement; second, they can use this information to combine the operational performance indicators with the specific characteristics of the countries of origin as described above. Finally, they could also calculate the transportation distance in tonne-kilometers. (Guenther and Greschner Farkavcová 2010).

3.3 Review of environmental management systems

After having analyzed the operational environmental performance and derived the main drivers, we extend the decision vector by adding the strategic perspective using EMS. An EMS does not focus on product attributes but proves that the certified company gives a high priority to the environment in general. EMSs assure that the company complies with environmental regulations. The EMS is institutionalized and intends continuous improvement of environmental performance as well as cost reduction and efficiency improvements. The certificate proves that the company adopts an advanced environmental strategy and approaches that are beyond command and control (Nash and Ehrenfeld 1997; Schaltegger et al. 2003). The ISO 14001 standard at the

[4] http://www.carbonfootprintofnations.com/content/calculator_of_carbon_footprint_for_nations/
[5] http://www.iea.org/stats/index.asp
[6] http://www.waterfootprint.org
[7] http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/data/waste-management/waste_treatment
[8] http://www.fao.org/nr/water/aquastat/main/index.stm

Table 2 Impact assessment of O.R. gowns by IFEU (1996)

	Reusable						Single use	
Material	Cotton		Blended fabric		Microfiber		Non-woven	
Use cycle	30 uc	75 uc	30 uc	75 uc	30 uc	75 uc	30 uc	75 uc
Cumulated energy cons. (MJ)	13,444	11,753	14,661	11,880	11,485	9,601	40,722	40,722
CO_2 (g)	828.00	713.00	671.00	713.00	569.00	555.00	2,081.00	2,081.00
VOC (g)	1.52	1.29	2.97	2.30	2.42	1.77	9.29	9.29
SO_2 (g)	1.12	0.95	1.43	1.10	1.30	1.02	6.40	6.40
NO_X (g)	1.19	0.98	1.85	1.51	1.89	1.61	6.51	6.51
Water cons. (l)	544.36	230.65	347.47	149.64	20.40	17.19	47.34	47.34
COD (g)	8.86	6.60	7.96	5.66	6.37	4.76	9.95	9.95
Waste (g)	812.00	624.00	714.00	476.00	610.00	432.00	2,419.00	2,419.00

CO_2 carbon dioxide, *COD* chemical oxygen demand, *NO_X* nitrogen oxide, *SO_2* sulfur oxide, *uc* use cycle, *VOC* volatile organic compounds

international level and the European Eco-management and Audit Scheme (EMAS) are the most widely accepted and used EMSs. Both EMSs are certified and regularly validated by an independent third party. Preliminary EMSs according to British Standard 8555 or the EN ISO 14005 document the first steps of the supplier towards a certified EMS. EMSs indicate to the procurer that the supplier has the technical capacity to meet high environmental standards (EC 2004). However, from the perspective of the procurer, the obtained certification does not reveal any information on the environmental performance of the product; a distinction between two suppliers awarded with the same certification of O.R. textiles is not possible, but the idea is to judge the level of engagement.

3.4 Review of eco-labels

"Environmental labels and declarations provide information about a product or service in terms of its overall environmental character, a specific environmental aspect, or any number of aspects. Purchasers and potential purchasers can use this information in choosing the products or services they desire based on environmental, as well as other, considerations." (DIN EN ISO 14020) In order to complete the picture, we add an external view to our internal operational and strategic assessment. Therefore, we analyze the extent to which the existing eco-labels applied to O.R. textiles really provide information about their overall environmental character. We identified the following eco-labels in the textile industry: the European Eco-label, the Oeko-Tex standard 100, and the Oeko-Tex Standard 100 plus (EC 2004, 2008; Targosz-Wrona 2009; Weber Marin and Tobler 2003; McCarthy and Burdett 2008).

The European Eco-label assures that "substances with harmful effects on the aquatic environment and air have been limited during fiber production, the risk of allergic reactions has been reduced, the product does not shrink more than conventional products and the product is as color resistant against washing, drying friction and light exposure as conventional products." The European Eco-label is

Table 3 Impact assessment of O.R. gowns by Schmidt (2000)

	Reusable						Single use			
Material	CO/PES/FC		PES/FC		PES/laminate		Pulp/PES/FC		Pulp/PES/PE	
Scenarios	bc	wc	bc	wc	bc	wc	bc	wc	bc	wc
Total energy consumption (MJ)	8.16	22.84	6.25	9.80	11.39	14.87	27.75	33.21	28.66	34.91
Renewable fuels (MJ)	1.91	1.91	1.91	1.91	1.91	1.91	8.97	8.97	8.96	8.96
Non-renewable fuels (MJ)	6.26	20.94	4.35	7.89	9.48	12.96	18.79	24.25	19.70	25.95
Water consumption (l)	60.10	60.10	11.00	11.00	17.30	17.30	43.10	43.10	43.50	43.50
Global warming potential (kg CO_2e)	0.38	1.75	0.25	0.54	0.60	1.09	0.54	1.01	0.57	1.10
Acidification potential (g SO_2e)	2.04	6.69	1.30	2.10	2.44	7.54	13.25	14.26	12.88	14.04
Eutrofication potential (g phosphate-e)	0.45	0.73	0.20	0.26	0.36	0.56	0.72	0.80	0.74	0.83

bc best case, *CO* cotton, *CO_2* carbon dioxide, *e* equivalent, *FC* fluorocarbon, *PE* polyethylene, *PES* polyester, *SO_2* sulfur oxide, *wc* worst case

Table 4 Impact assessment of O.R. drapes by Ponder (2009)

Material Use cycle	Reusable CO/PES 75 uc	Single use PP–SMS 75 uc
Net energy input (input–recovery) in MJ	65.05	225.95
CO_2 (kg)	5.71	20.50
NMVOC (kg)	0.02	0.06
SOx (kg)	0.02	0.04
NOx (kg)	0.03	0.07
Water consumption (kg)	1,373.83	0.00
Total solid emissions (kg)	0.42	0.92
Raw material consumption (kg)	2.34	7.27

CO cotton, *CO_2* carbon dioxide, *FC* fluorocarbon, *NMVOC* non-methane volatile organic compounds, *NOx* nitrogen oxide, *PES* polyester, *PP* polypropylene, *SMS* spunbond–meltblown–spunbond, *SOx* sulfur oxide, *uc* use cycle

released by the European Union Eco-labeling Board in collaboration with the European Commission and is revised regularly. The criteria focus on toxic substances, supplemented with some health aspects. Companies with certified products may use the European Eco-label logo for marketing and on the products (EC 2011a). As far as we know, only one producer of O.R. textiles is currently certified with the European Eco-label (EC 2011b).

The widely used Oeko-Tex standard 100 focuses on harmful substances as well. It guarantees that the textile will not negatively impact the health of the consumer. The textile is tested for substances that are prohibited or regulated by law, as well as for a number of additional substances that are known to pose health risks. The Oeko-Tex standard is released by a consortium of independent test institutes assembled in the International Oeko-Tex Association. But environmental aspects of the life cycle of the textiles (such as energy consumption) are not considered in the Oeko-Tex standard 100. Oeko-Tex 100 plus certification expands on the Oeko-Tex 100 certificate. In addition to the Oeko-Tex standard 100, the Oeko-Tex 100 plus requires an Oeko-Tex 1000 certificate, which is an EMS that is also released by the Oeko-Tex Association. We could identify a few producers who offer Oeko-Tex 100-certified O.R. textiles (Oeko-Tex 2011).

A comparison of the two eco-labels shows that both focus on toxic substances. The European Eco-label takes into account some additional criteria on the fibers, process, and chemical parameters (EC 2006, 2009; Targosz-Wrona 2009). The Oeko-Tex family considers environmental aspects only in the Oeko-Tex standard 100 plus or 1000 and not in the more widely used Oeko-Tex 100 standard. The European Eco-label requires information on three environmental aspects that are comparable with the key environmental aspects derived earlier: wastewater discharges from wet processing and energy and water use. The use of EMS is recommended but not required.

Public procurers in the European Union cannot require a specific eco-label, but they are explicitly allowed to use the underlying specifications of the eco-label for defining performance-based or functional environmental requirements (EC 2004, 2008). As the analysis above shows, the existing eco-labels applicable to O.R. textiles primarily focus on toxic substances. Other important environmental aspects, such as CO_2 and waste, are neglected, and energy and water are assessed on a voluntary basis. Concerning CO_2, first attempts can be observed, assessing how to integrate the carbon footprint in the European Eco-label (Baldo et al. 2009). A company awarded the European Eco-label has the right to use the European Eco-label logo on its products and for marketing purposes. From the perspective of the procurer, the eco-label does not disclose any information on how well the company is performing. The eco-label only shows that the company is in accordance with the corresponding criteria. Therefore, the exclusive consideration

Table 5 Impact assessment of O.R. drapes by IFEU (1996)

	Reusable						Single use	
Material	Cotton		Blended fabric		Microfiber		Non-woven	
Use cycle	30 uc	75 uc	30 uc	75 uc	30 uc	75 uc	30 uc	75 uc
Cum. energy cons. (MJ)	99,314	83,567	94,174	72,878	111,616	85,527	96,428	96,428
CO_2 (g)	6,037.00	5,075.00	5,110.00	4,154.00	5,940.0	4,716.0	3,886.0	3,886.0
VOC (g)	11.80	10.00	16.60	10.10	25.7	16.40	22.3	22.3
SO_2 (g)	7.20	5.70	8.80	6.10	12.2	8.10	15.2	15.2
NO_X (g)	8.70	7.10	10.10	7.30	19.6	15.70	16.7	16.7
Water cons. (l)	4,690.00	1,965.00	2,891.30	1,241.90	239.4	192.80	99.4	99.4
COD (g)	67.70	48.00	66.40	47.20	78.9	55.70	22.2	22.2
Waste (g)	6,163.00	4,210.00	5,830.00	3,890.00	7,057.0	4,672.0	3,735.0	3,735.0

CO_2 carbon dioxide, *COD* chemical oxygen demand, *NO_X* nitrogen oxide, *SO_2* sulfur oxide, *uc* use cycle, *VOC* volatile organic compounds

of eco-labels in procurement decisions is not advisable because existing labels focus solely on toxic substances at the exclusion of key indicators of environmental performance. Furthermore, a comparison of product alternatives based on eco-labels only is not possible because the needed information is undisclosed. The procurer needs not only information on the completion of the criteria but also information on how well the alternative product performs so that he can compare the alternatives and can choose the one with the lower environmental burden.

3.5 Decision vector

Green procurement requires sound information on the environmental aspects of products. From the existing LCAs for O.R. textiles, we could derive energy consumption, CO_2, water, and waste as key environmental aspects. The review of environmental management systems and eco-labels shows that both are important indicators of the general environmental commitment of a supplier but does not reveal indicators that allow the procurer to compare product alternatives on an ordinal scale. As illustrated in Fig. 2, we recommend soliciting information from the supplier on each of the key environmental aspects as well as on EMS, eco-labels, and the countries of origin. In order to assure comparability, the specifications need to be made in relation to one use cycle.

Depending on the market power of the organization and on the diffusion of LCAs, EMS, and eco-labels, we recommend flexibility in using the criteria. We will illustrate how to apply the decision vector in two exemplary cases (Table 6).

For the first case, we assume that the hospital is willing to procure green products but might not have enough resources to acquire all of the desired information. If a supplier can prove the existence of an EMS or can provide an eco-label,

$$\left\{ \begin{array}{cc} \boldsymbol{LCA} & \left[\begin{array}{cc} energy & MJ \\ CO^2e & kg \\ water & ltr. \\ waste & kg \end{array} \Big/ u.c. \right] \\ \boldsymbol{Ecolabel} & \left[\begin{array}{c} EEL \\ OekoTex \\ \ldots \end{array} \right] \\ \boldsymbol{EMS} & \left[\begin{array}{c} ISO\ 14001 \\ EMAS \\ \ldots \end{array} \right] \\ \boldsymbol{Countries\ of\ origin} & \left[\begin{array}{c} France \\ India \\ \ldots \end{array} \right] \end{array} \right\}$$

Fig. 2 The decision vector integrates the key information of the LCM instruments: LCA, eco-labels, and EMS as well as countries of origin

it will get one point. As soon as several suppliers provide information for the same criteria, the ranking must be revised. Therefore, the procurer must designate a ranking, r_i, for each supplier of the total number (n) of suppliers: the greener the performance of the procurer, the higher his rank. Based on the ranking, each supplier can be assigned a corresponding point score p_i using formula 1. Finally, the procurer will accept the supplier with the highest score.

$$p_i = \frac{1}{n-1} \times (n - r_i)$$

In the second case, we assume that the procurer can get all the data he requires and that the data are verifiable, complete, current, and based on a sound methodology. In a world of perfect information, the key environmental aspects need to be underpinned by a binding elicitation method based on the norm ISO 14021 (type II environmental declaration). The points are designated in accordance to formula 1, as well. The point scheme can easily be combined with economic or social criteria. Another possibility for flexible use of the criteria is the differentiation between prerequisite criteria and facultative criteria. Supposing that a sufficient number of suppliers can serve the necessary criteria, EMS and/or eco-labels can be defined as prerequisites.

For a more sophisticated assessment, the procurer can rank the identified operational performance indicators by applying multicriteria decision-making tools, like the Analytical Hierarchy Process, the Preference Ranking Organisation Method for Enrichment Evaluations, or the Hasse Diagram Technique (Belton and Stewart 2002).

4 Discussion

The main purpose of this article is to identify the most important environmental aspects of O.R. textiles and to combine them so that a procurer with limited resources and time obtains reliable decision criteria on which he can choose the alternative with the better environmental performance. The need for simplification as described in ISO 14067 and 14040 is also our main concern. Of course, the gathered data could be even more exploited in a more sophisticated approach. But in regard to tradeoffs between time effort for the procurer and a more sophisticated analysis, we argue that any further analyses would only add marginal benefit.

As described, it would be possible to calculate a national carbon footprint based on the energy consumption and the provenience of the textile. We decided not to integrate this aspect in our simple approach, because the provenience of a textile can be very difficult to define as the sector is largely relying on a worldwide division of labor and characterized by a diversified supply chain. Furthermore, only very little

Table 6 Exemplary application of the decision vector for O.R. textiles

Product	Unit	1. Case (incomplete information)				2. Case (complete information)			
		A	Points	B	Points	C	Points	D	Points
Energy consumption	MJ	60	1	80	0	60	1	80	0
CO_2e emissions	kg	–	0	–	0	2	0	0.5	1
Water consumption	l.	–	0	–	0	50	0	30	1
Waste	kg	–	0	–	0	4	0	3	1
EMS	Yes/no	Yes: EMAS	1	Yes: ISO	1	Yes: EMAS	1	Yes: ISO	1
Eco-label	Yes/no	Yes: EEL	1	No	0	Yes: EEL	1	Yes: EEL	1
Country	Nominal	France	1	India	0	France	1	India	0
Score			4		1		4		5

CO_2 carbon dioxide, *e* equivalent, *EEL* European Eco-label, *EMAS* Eco-Management and Audit Scheme, *EMS* Environmental Management System, *ISO* International Organization for Standardization

more information would be disclosed as we have already climate change relevant information included in our decision vector, in asking for the CO_2 equivalents. But of course, each supplier can easily integrate these or other relevant aspects.

Another refinement could be the consideration of qualitative aspects of the water consumption since a high water consumption is not necessarily related with a high wastewater generation as different countries have different degrees of wastewater treatment. The procurer would have to research in international databases to obtain this information. Therefore, we recommend to consider the origin of the textile and prefer national products but not to analyze this aspect in more detail. As well, no study in the review dealt with this aspect so far. Nevertheless, we added the databases that can be used for a more differentiated assessment.

5 Conclusions

The review of the existing LCAs on O.R. textiles has shown that it is not recommendable for a procurer to base his decision on existing LCAs. Besides methodological weaknesses, incompleteness, outdated data, and poor verifiability, the information provided is far too complex for procurement decisions regarding low-value products.

The second LCM instrument we reviewed was the EMS that proves the willingness of the supplier to integrate environmental aspects in their daily business, but it does not reveal how well a company is performing and is therefore not suitable for a comparison.

As a third LCM instrument, we reviewed the existing eco-labels applicable to O.R. textiles. This review has shown that the exclusive consideration of eco-labeling is not sufficient for a balanced green procurement decision because the existing eco-label systems focus mostly on toxic substances and ignore other key indicators of environmental performance. Therefore, we recommend revising the European Eco-label in two aspects: (1) Integrate more information on the key indicators of environmental performance and disclose the information as, for example, on the nutrition fact labels on food, and (2) integrate EMS as a requested criterion.

The need to improve and downscale the LCM instruments to the needs of procurers is obvious. Therefore, we derived the key indicators of the environmental performance, CO_2, energy, waste, and water, of the existing LCAs and paved the way for the development of a new eco-label for O.R. textiles. The four key environmental indicators reflect the classic environmental concerns of water and air pollution, waste reduction, and the finiteness of non-renewable resources and constitute an alternative to the simplistic footprint approaches. In combination with a consideration of EMSs, eco-labels, and the countries of origin as illustrated in the decision vector, the procurer can easily consider environmental aspects in his procurement decisions. In our opinion, the decision vector optimally balances the information density between overcomplexity and oversimplification and should be the basis for future development of an eco-label for O.R. textiles. The same methodology presented here for O.R. textiles can be applied for any type of low-value products.

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